# *Zero-Crossing Detection with False Trigger Avoidance*


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### Overview

A zero-crossing detector (ZCD) is used for detecting zero-crossing of AC signals. Applications of ZCDs include the use in protection relays, AC analog input modules, smart energy meters, power quality analyzers, frequency measurement, phase measurement, and control of power electronic circuits that must be switched relative to the AC waveform. This application note details the performance of the ZCD module in the ADS7x28 device family.

### Harmonics and Transients in AC Mains

AC mains signal contains harmonics or transients or a combination of both. Harmonics are caused by nonlinear loads such as a saturated inductor or a capacitor with a large voltage coefficient (that is dryers and refrigerators). Transients can occur due to switching of loads which may cause voltage transient due to a sudden surge in current demand. High frequency harmonics and transients may cause multiple zero-crossings leading to false triggers. ZCD circuits using comparators are not immune to such transients and harmonics. AC mains may have up to 40% total-harmonic-distortion (THD). For robustness, the ZCD circuit may be designed assuming 60% THD in AC mains.

### Impact of Harmonics and Transients on ZCD Circuit

Figure 1 shows a comparator-based ZCD circuit and Figure 2 shows the output waveform for a sine wave input.

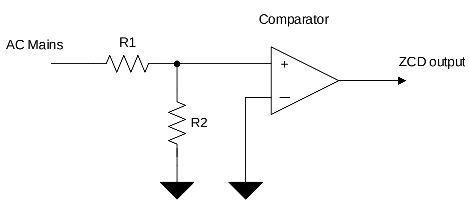


**Figure 1. ZCD Circuit Using Comparator**

The ZCD circuit in Figure 1 does not work as expected when a sine wave input contains distortion. A distorted sine wave may contain transients and high-frequency harmonics which can cause multiple zero-crossings near the actual zero-crossing of the AC signal. For a distorted sine signal input, the ZCD circuit produces false triggers as shown in Figure 3.

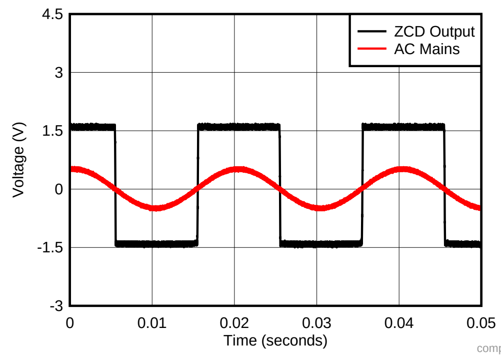


**Figure 2. ZCD Output Corresponding to Ideal AC Mains**

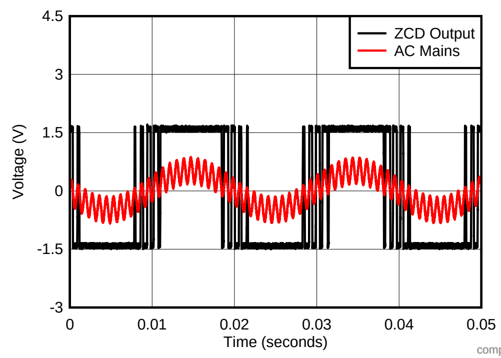


**Figure 3. ZCD Output Corresponding to Distorted AC Mains**

Hysteresis is used in ZCD comparator circuits, shown in Figure 4, to prevent multiple zero-crossing detection, as shown in Figure 5. The limitations of this type of ZCD circuit are the resultant phase shift between the AC mains and the ZCD output, and zero-crossing threshold drift over operating temperature range.

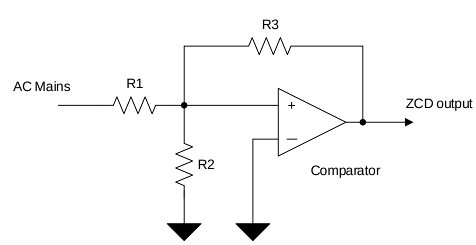


**Figure 4. ZCD Circuit Using Comparator with Hysteresis**

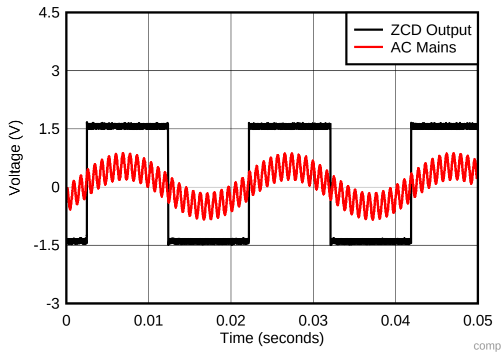


**Figure 5. ZCD Circuit with Hysteresis Output Corresponding to Distorted AC Mains**

An alternative solution to preventing multiple zero-crossing detection is to introduce transient rejection time after the detection of a zero-crossing by the ZCD circuit. During the transient rejection time, output of the ZCD circuit does not change in response to zero-crossing of the input. The transient rejection time should mask the entire region of possible multiple zero-crossings. Multiple zero-crossings occur when the magnitude of the fundamental frequency sine wave is less than the peak total of harmonics. For sinusoidal signals, the transient rejection time can be calculated by Equation 1.

$$\text{transient rejection time} = 2 \times \frac{\sin^{-1}\left(\frac{\text{peak of harmonic distortion}}{\text{peak of fundamental harmonic}}\right)}{2\pi f}\ \text{seconds} \quad (1)$$

where

- f = frequency of the fundamental signal (that is the AC mains)

## ADS7x28 based ZCD with Configurable Transient Rejection Time

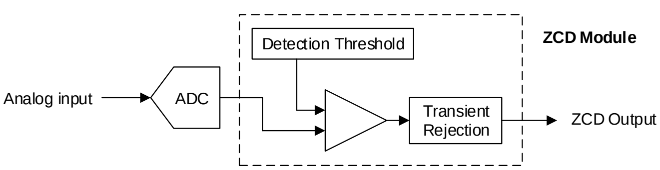


**Figure 6. ADS7x28 ZCD Block Diagram**

The ADS7x28 is a family of devices that features an integrated ZCD module with a configurable transient rejection time (see Table 1). The zero-crossing-detection (ZCD) module generates a digital output corresponding to the detection threshold crossings of an analog input (see Figure 6). The detection threshold is the digital threshold, used by the digital window comparator, for comparison with the ADC conversion result. The analog input range of the ADS7x28 is unipolar (0 V to AVDD, hence the attenuated AC mains signal must be biased accordingly.

## Harmonics and Transient Rejection

Transients near zero-crossings can be rejected by configuring the ZCD transient rejection time in ADS7x28. The value to be written to the ZCD_BLANKING register can be calculated using Equation 2.

$$\text{ZCD\_BLANKING} = f_{SAMPLE} \times \text{transient rejection time} \quad (2)$$

where

- $f_{SAMPLE}$ is the sampling rate of the ADC

For demonstration, consider f = 50 Hz , $f_{SAMPLE}$ = 10.4 kHz, and 60% total-harmonic-distortion (THD). From Equation 2, ZCD_BLANKING = 43 to achieve transient rejection time of about 4.13 ms. Figure 7 shows the output waveform of ADS7x28 ZCD with transient rejection time of 4.13 milliseconds and a distorted sine wave input. The ZCD output does not contain multiple zero-crossings even though the input crosses the detection threshold multiple times.

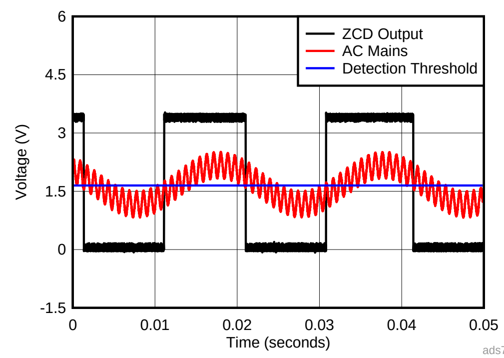


**Figure 7. ADS7x28 ZCD Output Corresponding to Distorted AC Mains**

## Conclusion

Transient rejection time near the zero-crossing detection threshold can improve the robustness of ZCD circuit when used with distorted AC mains. The transient rejection time can be computed for the desired input waveform type and proportion of the harmonic distortion expected. The ADS7x28 features a transient rejection module to prevent multiple zero-crossing detection, caused by transients and harmonics, and phase delay. The characteristics of the transient rejection module in the ADS7x28 are software configurable, so they can be modified as per AC mains conditions.

**Table 1. ADCs with ZCD Module**

| DEVICE | DESCRIPTION |
|---|---|
| ADS7128 | Small, 8-channel, 12-bit ADC with $I^2C$ interface |
| ADS7028 | Small, 8-channel, 12-bit ADC with SPI interface |